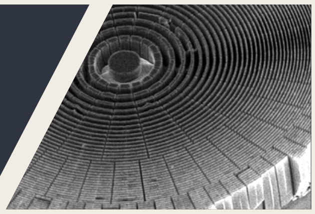
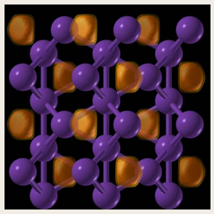
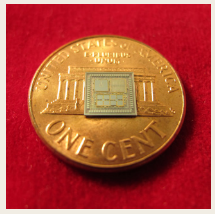
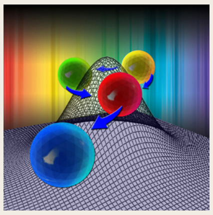
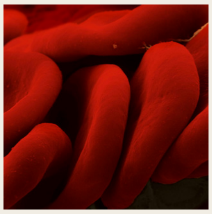
   

BREAKTHROUGH TECHNOLOGIES FOR NATIONAL SECURITY

Defense Advanced Research Projects Agency

March 2015

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BREAKTHROUGH TECHNOLOGIES FOR NATIONAL SECURITY

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www.darpa.mil

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
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ARLINGTON, VA 22203-2114

March 2015

A century and a half ago, Franz Liszt said his purpose in composing music was "to cast a javelin into the infinite spaces of the future." Our muse at DARPA is technology and our objective is national security, but we are motivated by that same irrepressible urge. DARPA's people come through the front door each day to imagine a better future, to drive technology in pursuit of that future, to launch new trajectories of U.S. capability. We come to change what's possible.

We are able to achieve this objective only because of the strong support and commitment we earn from Congress and the White House; from Defense Department leadership, the military Services, and our partners in the department's science and technology community; and from the engineers and scientists in companies, universities, and other organizations who make new technologies come true. We've written this document to share with that extended community and the American public DARPA's mission and current areas of focused investment.

Thank you for your engagement. We are confident that, together, we can create amazing opportunities for our Nation and for the world.

Arati Prabhakar

Arati Prabhakar
Director

Steven H. Walker
Deputy Director

FOR MORE THAN FIFTY YEARS, DARPA HAS HELD TO A SINGULAR AND ENDURING MISSION: TO MAKE PIVOTAL INVESTMENTS IN BREAKTHROUGH TECHNOLOGIES FOR NATIONAL SECURITY.

The genesis of that mission and of DARPA itself dates to the launch of Sputnik in 1957, and a commitment by the United States that, from that time forward, it would be the initiator and not the victim of strategic technological surprises. Working with innovators inside and outside of government, DARPA has repeatedly delivered on that mission, transforming revolutionary concepts and even seeming impossibilities into practical capabilities. The ultimate results have included not only game-changing military capabilities such as precision weapons and stealth technology but also such icons of modern civilian society as the Internet, automated voice recognition and language translation, and Global Positioning System receivers small enough to embed in myriad consumer devices.

DARPA explicitly reaches for transformational change instead of incremental advances. But it does not perform its engineering alchemy in isolation. It works within an innovation ecosystem that includes academic, corporate and governmental partners, with a constant focus on the Nation's military Services, which work with DARPA to create new strategic opportunities and novel tactical options. For decades, this vibrant, interlocking ecosystem of diverse collaborators has proven to be a nurturing environment for the intense creativity that DARPA is designed to cultivate.

DARPA's mission and philosophy have held steady for decades, but the world around DARPA has changed dramatically—and the rate at which those changes have occurred has in many respects increased. Those changes include some remarkable and even astonishing scientific and technological advances that, if wisely and purposefully harnessed, have the potential not only to ensure ongoing U.S. military superiority and security but also to catalyze societal and economic advances. At the same time, the world is experiencing some deeply disturbing technical, economic and geopolitical shifts that pose potential threats to U.S. preeminence and stability. These dueling trends of unprecedented opportunity and simmering menace—and how they can be expected to affect U.S. national security needs a decade and more from now—deeply inform DARPA's most recent determination of its strategic priorities for the next several years.

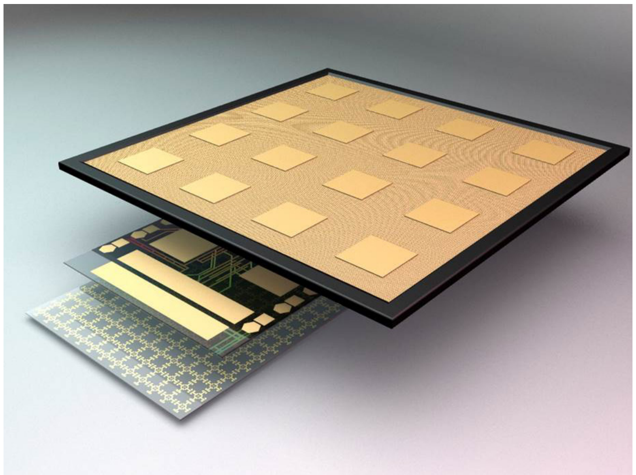
OPERATING IN A GLOBAL CONTEXT

It is important to start from the undeniable premise that America is in a very strong position today and is endowed with enormous advantages as it enters the last decade before its 250th birthday. But DARPA's mission is to look beyond the reality of today and to focus on the potentiality of the future. Specifically, its job is to identify current or future advances that have the potential to bend today's security trajectories—advances that, years from now, could disrupt the stability the Nation enjoys today as well as advances that, over the same period, could enhance national and global stability.

Looking through the first of those two lenses, DARPA sees the beginnings of some daunting challenges. On the technology front, the Nation faces the challenge of maintaining domestic superiority even as sophisticated components and systems once available almost exclusively to U.S. forces become increasingly available on the global market. This reality is largely the result of otherwise beneficial economic forces that have made once-proprietary products less expensive and more accessible. But the commodification and off-the-shelf availability of weapons technology, biological and chemical threat capabilities, advanced microelectronics and cyber- and space-related technologies represent an historic shift that raises the stakes for the United States. Among other implications, it drives home the point that advanced hardware alone is no longer a guarantee of military and economic success; increasingly, the nation or non-state player that makes the smartest and most strategic use of that hardware will dominate.

Communication capabilities, too, have undergone radical democratization in recent years, making it exceedingly easy through social media and other channels for otherwise-modest undercurrents of conflict or misinformation to blossom into deadly crises. And while the still nascent synthetic biology and biotechnology fields remain specialized domains requiring well-equipped laboratories and skilled researchers, the fields show early signs of a future in which off-the-shelf gene-screening and -splicing kits will make the tools of genetic engineering accessible to many, elevating concerns on the biodefense front.

Challenges relevant to DARPA's work also loom on the geopolitical front, at multiple scales. Some of those challenges involve peer adversaries and other nation states and encompass conventional-weapon threats as well as concerns about nuclear proliferation. Other challenges stem from terrorist groups and other non-nation-state actors. These groups pose unique risks in part because they operate outside the bounds of international conventions and so are less responsive to conventional approaches to deterrence. Still other challenges have their roots in global social, economic and environmental trends that are affecting governments and populations worldwide. These include demographic shifts, such as population growth and urbanization in developing countries and the aging of populations in developed countries; religious and cultural shifts, including the rise of violent extremism; resource imbalances and shortages, including especially those involving energy sources and fresh water; stresses related to climate change, including sea-level rise, drought and flooding, with special concerns about potential impacts on infrastructure and agriculture; and the growing potential for fast-moving human and animal pandemics and other health threats, with their associated risks of economic depletion, loss of trust in leadership, and social unrest.



DARPA's programs are developing the building blocks of the next generation of compact, powerful radio-frequency systems for radar, communications and electronic warfare. These arrays can significantly reduce development times for the sophisticated RF systems on which our military depends.

These social, economic and geopolitical trends are being driven by enormously complex forces including new technologies, but technology can be a part of the solution as well, helping to ensure that these trends do not undermine U.S. and international stability. Indeed, a number of achievements with roots in DARPA research are opening new avenues for counterbalancing these trends and advancing U.S. national security in the years ahead.

In the military domain, advances in microelectronics and communications are making possible a degree of networked coordination almost unimaginable just a few years ago. This in turn is enabling the creation of nimble, distributed, modular systems with significant potential advantages over today's centralized and overburdened tactical platforms. Advances in physics and chemistry are making possible the manufacture of new materials with novel properties, facilitating the design and construction of such futuristic devices as portable cold-atom clocks, with their potential to revolutionize timing and navigation.

Similarly, the rapid decoding of genomic sequences and harnessing of biological processes—not just for medical applications but also for the creation of novel chemistries, bio-mechanical devices and biological interfaces—is unlocking innovative potential in fields as diverse as prosthetics, neurotechnology, materials, diagnostics, vaccines and therapeutics.

And in the digital arena, the application of formal methods and related advances in mathematics and computing hold out promise for overcoming the increasingly costly albatross of cyber insecurity and related threats to physical infrastructure and financial and social institutions. At the same time, big data analytics are offering glimpses of a possible future in which sophisticated models will be able to recognize the first inklings of epidemics, ailing ecosystems and even potentially dangerous geopolitical threats, allowing time to mitigate looming impacts.

Technology has repeatedly proven its potential to help reshape the national security landscape. U.S. nuclear weapons offset the Soviet Union's conventional troop advantage early in the Cold War and the development of precision munitions redefined U.S. capabilities in more recent decades. Similarly, technological advances that leapfrog current states of the art will be essential to assure ongoing U.S. superiority in the years and decades ahead.

SETTING A NEW PACE

A single cross-cutting quality of modern life and technology infuses all of the above threats and opportunities, and is a core target and driver of DARPA's work today: the phenomenon of increasing pace. DARPA's strategy for countering technology-related challenges—and for taking advantage of related opportunities—revolves around a core goal of harnessing pace and being fueled by it, rather than being ultimately exhausted by it.

The strategic centrality of pace is evident today in every security-related domain and at every time scale.

In its most literal manifestation, pace matters on the battlefield, where the need for detailed, dynamic, real-time situational awareness and action are critical. Communications must be instant and accurate. Intelligence must be up to date—which today means not just up to date but up to the moment. And weapons must close on target before the adversary moves.

But the growing emphasis on pace is also manifesting on the very shortest and longest of time scales. At the micro- and nanosecond time scales at which our information and radio frequency (RF) systems operate, the rate at which information is being gathered increasingly exceeds capacities for manual analysis and response. And at the other end of the temporal spectrum—the decades it currently takes to design, develop and deploy new complex weapons systems—there is growing appreciation of the

DARPA BY THE NUMBERS

- **$2.9B budget in FY 2015**
- **219 government employees, including 94 technical program managers**
- **250 programs across six technology offices**
- **2,000 contracts, grants and other agreements with companies, universities, and Department of Defense (DoD) and other laboratories**

need to change the pace, with movement toward nimble, modular, functionally coordinated weapons platforms that can be more rapidly deployed and upgraded than current systems.

In these areas and others, DARPA will pursue the strategic imperative of pace in part by continuing to be a bold, risk-tolerant investor in high-impact technologies, so the Nation can be the first to develop and adopt the novel capabilities made possible by such work. Even marginally early adoption of significant new capabilities can make outsized differences in outcomes—nuclear weapons and radar technology being prime examples. For this reason, DARPA is committed not only to creating new potential technologies but also to helping transition those technologies to the Services or other sectors where they can be implemented in support of national security. This will enable the United States to effectively outpace an adversary's "OODA" loop, iteratively observing, orienting, deciding and acting more quickly than those seeking to get inside ours.

DARPA'S INVESTMENT PORTFOLIO

DARPA's strategic priorities can be grouped within four areas, described here with examples of the kinds of capabilities that the agency and its partners aim to enable.

RETHINK COMPLEX MILITARY SYSTEMS

Modern weapons today are spectacularly complex, and the multipurpose platforms on which they reside only add to the enormity of this complexity. To be sure, these systems are immensely powerful and have been overwhelmingly successful to date. But there is growing evidence that, under current practices the benefits of these remarkably complex architectures are being undermined by inherent drawbacks. Today, for example, high-end weapons platforms are so complex they take decades to produce and years to upgrade. But in a world in which pace is inexorably increasing, and in which other economic and manufacturing sectors have recognized the benefits of systems modularity, rapid-fire iterative improvements and faster hardware- and software-system upgrades, the military's current approach to harnessing complexity is outdated and inadequate and risks leaving the Nation vulnerable to adversaries developing more nimble means of adopting the latest technologies.

To address this shifting landscape, DARPA is working to achieve new capabilities relating to the following challenges:

• Assuring Dominance of the Electromagnetic Spectrum

After decades in which the United States enjoyed overwhelming dominance of the electromagnetic spectrum, other nations are catching up quickly, in part because of the growing commercial availability of remarkably powerful technologies. To reassert electromagnetic dominance, DARPA is developing advanced algorithms to identify and counter unanticipated enemy radars in real time; fully configurable RF systems so that communications, radar and electronic warfare can share precious spectrum; and new defense-related electronic platforms for sensing and imaging.

• Improving Position, Navigation, and Timing (PNT) Without GPS

Fine-grained PNT is no longer a luxury for the warfighter; it is absolutely essential. That has turned the sophisticated satellite signals on which PNT depends into potential vulnerabilities. To address this concern, DARPA is developing a family of highly precise and accurate navigation and timing technologies that can function in GPS-denied environments and enable new cooperative and coherent effects from distributed systems.

• Maintaining Air Superiority in Contested Environments

U.S. military reach has long rested in large part on our Nation's unchallenged standing as the world's preeminent air power, but new and increasingly available technologies are posing unprecedented threats to that status. Warfighters and technologists alike understand that no single new capability can deter and defeat the sophisticated and numerous adversary systems under development. Instead, future U.S. capabilities will require an integrated system of intelligence, surveillance and reconnaissance (ISR); weapons; communications; electronic warfare; cyber and other advanced technologies. At the same time, the air platforms that carry these mission systems to theater will continue to need greater range, survivability and payload capacity.

DARPA is planning an effort to develop and fly X-plane prototypes to show what is possible with new air platform technologies. The program will work closely with the Air Force and Navy and aims to provide the pivotal demonstrations that can inform their future aircraft system acquisitions. DARPA is also developing new system-of-systems architectures and experimentation tools to explore modular, distributed and coherent mission systems. These approaches offer the potential to speed development and upgrade cycles—while delivering the powerful effects needed to prevail in a highly contested environment.

• Leading the World in Advanced Hypersonics

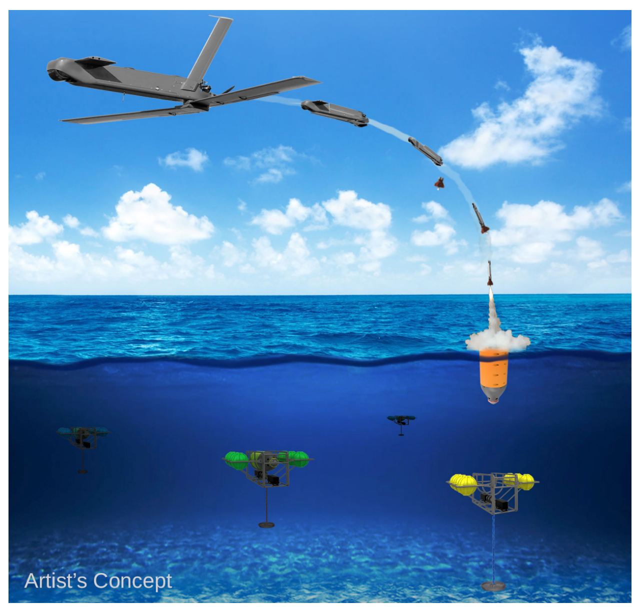
Precise warhead delivery at hypersonic velocities is a significant opportunity to change the pace of warfare. DARPA is developing unprecedented hypersonic capabilities to provide new U.S. response options, and to prevent peer adversary strategic surprise.

• Asserting a Robust Capability in Space

The United States is reliant on space for virtually every essential security mission, but U.S. space capabilities have not kept up with rapid global changes. DARPA is developing new approaches to launching satellites into orbit on short notice and at low cost, including by means of reusable first-stage and space-plane systems, which have the potential to enable launch of satellites from virtually anywhere with just 24 hours' notice and at a fraction of current costs. The Agency is also demonstrating technologies to enhance the Nation's current limited capabilities relating to space domain awareness.

• Enhancing Maritime Agility

Oceans are strategically central but almost incomprehensibly large, demanding innovative approaches to achieve strategic leverage. DARPA is developing an unmanned maritime surface vessel optimized to continuously and overtly trail threat submarines; unmanned undersea platforms for scalable operations; and novel technologies to



The Upward Falling Payloads (UFP) program centers on developing deployable, unmanned, distributed systems that could lie on the deep-ocean floor for years at a time. These deep-sea nodes could then be recalled remotely when needed and "fall upward" to the surface. The goal is to support the U.S. Navy with distributed technologies anywhere over large maritime areas.

enable take-off and landing of long-endurance unmanned aerial vehicles aboard smaller ships.

• Exerting Control on the Ground

As terrorists and insurgents gain access to increasingly sophisticated technology, it is essential that U.S. ground forces complement their superior armor and firepower with equally advanced means of being flexible and adaptive. To deliver these traits and greater potential for surprise, DARPA is researching radically redesigned ground vehicles for troop support, including technologies for a new-generation combat vehicle with enhanced mobility and survivability. The agency is also developing a range of squad overmatch capabilities to help ground forces expand their reach, situational awareness and maneuverability.

• Augmenting Defense Against Terrorism

Small-scale terrorist actions can have outsized impacts, demanding technologies able to detect the earliest evidence of a planned attack. In response to this challenge, DARPA is developing advanced capabilities to counter new types of mass-terror threats in the radiological, cyber and life-science domains. Among other approaches, it is developing and testing networked, mobile and cost-effective nuclear- and radiological-weapons detectors that can easily be deployed to provide real-time surveillance over city-scale areas.

MASTER THE INFORMATION EXPLOSION

Global digital data is in the midst of a seemingly boundless growth spurt. Every minute of every day, more than 300 hours of video is uploaded to YouTube and hundreds of new websites are launched. Nearly 5×10^{22} bytes of digital data are predicted to be generated by 2020—about ten times the current volume. And of the approximately 5×10^{21} bytes created as of 2014, an estimated 90 percent was generated in the previous

THE SOCIETAL IMPLICATIONS OF NEW TECHNOLOGIES

Because DARPA's programs push the leading edge of technology, they are sometimes society's first notable encounter with the societal dilemmas associated with new capabilities. DARPA pursues these technologies because of their promise, and the Agency is committed to exploring domains that could leave the Nation vulnerable if not pursued. But DARPA's leadership and team members also understand that, in this pursuit, the Agency's work will at times raise ethical, legal, security or policy questions that cannot and should not go unaddressed. What are the privacy considerations in using public data to identify security threats, and under what conditions might it be justifiable to develop and test technologies that can infer such private or personal matters as intention or attitude or trustworthiness? How can society guard against misuse of new synthetic biology capabilities, including intentional mischief and accidental release?

In dealing with issues such as these, DARPA's job is twofold: First, the Agency must be fearless about exploring new technologies and their capabilities; this is DARPA's core function, and the Nation is best served if DARPA pushes critical frontiers ahead of its adversaries. At the same time, DARPA is committed to addressing the broader societal questions raised by its work and engaging those in relevant communities of expertise to provide context and perspective for consideration. DARPA works rigorously within the law and regulations and with appropriate organizations where legal and policy frameworks already exist. In new and uncharted territory, the Agency engages a variety of experts and stakeholders with varying points of view—both to hear what they and their professional communities of practice have to say and to help convey to those communities DARPA's insights about what technology can and cannot do.

Societal consensus on difficult questions of technology and policy is notoriously difficult to achieve. And while new technologies can help defuse previously polarizing issues—it is possible, for example, that technology will eventually help manage the problem of assuring privacy, even though technology today has exacerbated that problem—it is important to recognize that technological advances are bound to keep generating new societal quandaries, and that resolving them will demand broad community engagement.

Computer security experts from academia, industry and the larger security community have organized themselves into more than 30 teams to compete in DARPA's Cyber Grand Challenge—a first-of-its-kind tournament designed to speed the development of automated security systems able to defend against cyberattacks as fast as they are launched. DARPA's Cyber Grand Challenge final competition will be held in 2016 in conjunction with DEF CON, one of the largest computer security conferences in the world.

two years alone. Adding to this widely available information is the deluge of bits generated by military and intelligence sensors.

This accelerating glut of information—and the Nation's increasing reliance on information systems in every sector of society—presents a challenge and an opportunity. The opportunity is to derive from this massive trove the myriad associations and causalities that, once unveiled, can provide insights into everything from the predicted arrival of a new strain of influenza to the plans for a terror attack halfway around the globe. The challenge—virtually the same as the opportunity—is how to separate signal from noise in order to derive these insights, and how to know when to trust the information in hand.

To address these issues, DARPA is working to achieve new capabilities relating to the following challenges:

• Deriving Meaning From Big Data

Increasingly, the bottleneck to wise decision making is not a lack of data but a lack of capacity to identify and understand the most important data. Toward this end, DARPA is developing novel approaches to deriving insights from massive datasets and to mapping behavior patterns at scale, including algorithms to quickly identify anomalous threat-related behaviors of systems, individuals and groups. The Agency is also developing technologies to provide comprehensive awareness and understanding of the cyber battlespace; automated computational capabilities to detect hidden causal relationships; search technologies for discovery, organization and presentation of domain-specific content; software to detect, classify, measure and track the spread of ideas and concepts on social media; and methods for automating the analysis of photos and videos. DARPA's goal is to enable the operational user of information with powerful big-data tools.

• Building Trust Into Information Systems

Information has always been part of the warfighter's arsenal. But the ease and efficiency with which code, text, images and other forms of data can today be manipulated has raised the stakes enormously, demanding new methods for assessing what information to trust and how to protect the integrity of data. DARPA is developing technologies to ensure that the data upon which critical decisions are made is trustworthy. That includes more effective and user-friendly user identification and authentication technologies; advanced applications of formal methods and related mathematics-based verification techniques to produce operating systems for embedded devices that are unhackable for specified security properties; automated cyber defense capabilities to identify and respond to cyber attacks more rapidly than current methods and radically reduce the return on investment for hackers; and new approaches to building trusted systems from an inherently untrustworthy global supply chain.

HARNESS BIOLOGY AS TECHNOLOGY

The recent maturation of genetic technologies and bioinformatics, in conjunction with recent breakthroughs in neuroscience, immunology and related biomedical fields, have begun to erase the longstanding gap between the life sciences, engineering and computing disciplines. This synthesis is catalyzing the creation of a new interdisciplinary domain rich with potential breakthroughs in areas as diverse as mental health and materials science.

Recognizing that this largely unexplored opportunity space is ripe for early, game-changing attention, DARPA in 2014 created its Biological Technologies Office, which has enabled a new level of momentum for DARPA's portfolio of innovative, bio-based programs.

To accelerate discoveries in these areas, DARPA is working to achieve new capabilities relating to the following challenges:

• Accelerating Progress in Synthetic Biology

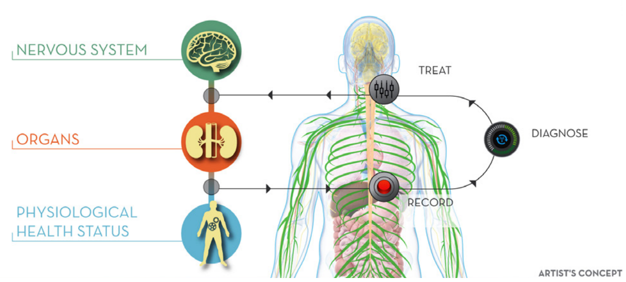
Biological systems have evolved tremendously sophisticated and highly efficient approaches to synthesizing compounds, including some with the potential to address current challenges in fields ranging from medicine to materials science. DARPA is developing technologies to harness biology's synthetic and functional capabilities, with the goal of creating revolutionary bio-based manufacturing platforms that can enable new production paradigms and create materials with novel properties.

• Outpacing Infectious Diseases

As the 2014 Ebola outbreak demonstrated, emerging infectious diseases can be a significant threat not just to health but also to national stability. Yet even as the number of emerging diseases has increased, posing threats to U.S. interests abroad and at home, there has been a decline in the rate of development of novel antimicrobial agents. In response, DARPA is developing unconventional biological approaches to reduce the threats posed by infectious disease. Among the Agency's goals are the development of genetic and immunological technologies to detect, diagnose and treat infectious diseases with unprecedented precision and rapidity, and platforms for exploring the evolution of viruses, predicting mutational pathways and developing drugs and vaccines in advance of need.

• Mastering New Neurotechnologies

Recent advances in microelectronics, information science and neuroscience are enabling the development of novel therapies to accelerate recovery after a range of injuries and, in the longer run, new approaches to optimizing human performance. Among the Agency's goals in this domain are implantable neural interfaces for human clinical use to bridge gaps in the injured brain, help overcome memory deficits and precisely deliver therapeutic stimuli in patients with neuropsychiatric and neurological disease; and systems to provide sensor-enabled feedback from prosthetic hands to the nervous system to provide enhanced dexterity and even the sense of touch for amputees.



DARPA's Electrical Prescriptions (ElectRx, pronounced "electrics") program aims to develop ultraminiaturized feedback-controlled neuromodulation technologies that would monitor health status and intervene as needed to deliver patient-specific therapeutic patterns of stimulation designed to restore a healthy physiological state. Peripheral neuromodulation therapies based on ElectRx research could help maximize the immunological, physical and mental health of military Service members and veterans.

EXPAND THE TECHNOLOGICAL FRONTIER

From its earliest days, DARPA's core work has involved overcoming seemingly insurmountable physics and engineering barriers and, once showing those daunting problems to be tractable after all, applying new capabilities made possible by these breakthroughs directly to national security needs. That tradition holds true today.

Maintaining momentum in this core component of the agency, DARPA is working to achieve new capabilities relating to the following opportunities:

• Applying Deep Mathematics

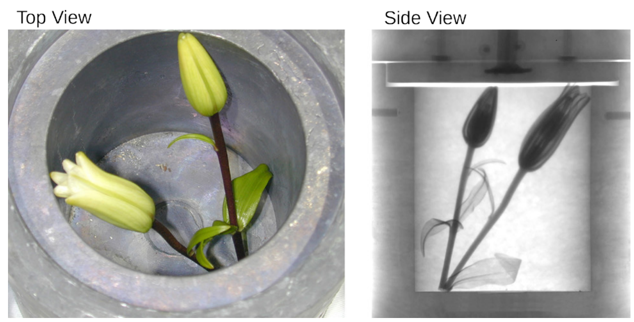
From cyber defense to big data analysis to predictive modeling of complex phenomena, many practical technological challenges are short of solutions because the relevant mathematics remain incomplete. Among other initiatives aimed to address such shortcomings, DARPA is constructing and applying new mathematical approaches for representing, designing, and testing complex systems and, separately, is developing new mathematical tools for modeling extremely complex systems quickly without sacrificing resolution.

• Inventing New Chemistries, Processes and Materials

Military systems are fundamentally limited by the materials from which they are made. Only rarely, however, do any of the many new materials developed in laboratories make the transition into operational systems. To facilitate the assessment and adoption of novel materials in practical settings, DARPA is pursuing new modeling and measurement tools for evaluating and predicting functional reliability and is developing low-cost fabrication methods to allow customized and small-volume production. DARPA is also creating the technologies needed to assemble systems directly from atomic-scale feedstock.

• Harnessing Quantum Physics

Recent advances in the precision engineering of light and matter systems, together with a deeper understanding of their collective quantum behaviors, offer unprecedented control over new classes of materials and devices. DARPA is advancing quantum technologies—including precision engineering of nanoscale and quantum opto-electro-mechanical structures and precision control of cold atoms through optical cooling techniques—to bring about new capabilities in navigation and timing, chem-bio detection, communication and information processing, and metrology, and unprecedented degrees of control over the electromagnetic spectrum, critical for electronic warfare and other applications.



DARPA's Intense and Compact Neutron Sources (ICONS) program seeks to develop portable, next-generation imaging tools that combine the complementary benefits of X-ray and neutron radiography to enable highly detailed scanning in field settings. Neutron scanning provides the capability to see through many otherwise visually impenetrable objects; Asiatic lilies in a lead cask (left) are invisible to x-ray imaging but clearly visible in high resolution via neutron imaging (right).

KEEPING DARPA VIGOROUS

DARPA's leadership takes seriously its responsibility to maintain and encourage the agency's culture of innovation and its ability to execute rapidly and effectively.

At the center of DARPA's success is an abiding commitment to identify, recruit and support excellent program managers—extraordinary individuals who are at the top of their fields and who are hungry for the opportunity to push the limits of their disciplines. Program managers come from academia, industry and government agencies for limited stints, generally three to five years. That deadline fuels the signature DARPA urgency to achieve success in less time than might be considered reasonable in a conventional setting.

Contributing to that sense of urgency is the understanding that, at DARPA, programs that fall short of expectations are not given the luxury of long, slow retirements. It is understood at DARPA that if the Agency is going to differ from others by tackling more difficult challenges and taking bigger risks, then it must also be willing to acknowledge when a goal is proving unachievable, at least with current technologies. In those cases, resources are redirected to problems likely to prove more tractable.

Program managers address challenges broadly, spanning the spectrum from deep science to systems to capabilities. They are driven by the desire to make a difference and recognize that success comes from working effectively with others. They define their programs and set milestones, such as deadlines for the submission of designs or for the achievement of goals at designated stages of project maturity. They are also constantly probing for the next big thing in their fields; in addition to meeting regularly with their performers at sites at which DARPA's work is being done, they communicate with leaders in the scientific and engineering community to identify new challenges and their potential solutions.

Program managers report to DARPA's office directors and their deputies, who are responsible for charting their offices' technical directions, hiring program managers and overseeing program execution. The technical staff is also supported by experts in security, legal and contracting issues, finance, human resources and communications. These are the people who make it possible for program managers to achieve big things during their relatively short tenures.

At the Agency level, the DARPA Director and Deputy Director approve each new program and review ongoing programs, while setting Agency-wide priorities and ensuring a balanced investment portfolio.

DARPA benefits greatly from special statutory hiring authorities and alternative contracting vehicles that allow the Agency to take quick advantage of opportunities to advance its mission. These legislated capabilities have helped DARPA continue to execute its mission effectively.

On top of these structural and administrative strengths, DARPA embraces a culture of collegial ambitiousness that encourages its scientists, engineers, mathematicians and others to pursue their highest professional dreams and achieve their personal bests. At the same time, DARPA focuses

The Airborne Launch Assist Space Access (ALASA) program seeks to propel 100-pound satellites into orbit for less than $1 million per flight by using low-cost, expendable upper stages launched from unmodified conventional aircraft. ALASA aims to provide more affordable, flexible and reliable access to space.

heavily on building collaborative communities of expertise in institutions across the country. This approach helps the Nation by encouraging work at the boundaries and intersections of conventional disciplines, while making the Agency itself an enormously supportive, interactive and satisfying place to work.

Ultimately, what motivates the people of DARPA more than anything else is the opportunity to passionately pursue their consuming interests within the uniquely gratifying context of public service. Rare is the opportunity to contribute so directly to the Nation's wellbeing while having the privilege of exploring, day after day, the very frontiers of human knowledge. It is this spirit of service, elevated by the thrill of discovery, that suffuses every office in DARPA and that fuels, and will continue to fuel, DARPA's success.

MAKING A DIFFERENCE—FROM CONCEPT TO REALITY

DARPA's mission is to reveal new possibilities and enable groundbreaking capabilities by developing and demonstrating breakthrough technologies, but true success happens only when these technologies make significant, transformative improvements in the Nation's security. That's why, even before a program launches, DARPA starts developing strategies for transitioning anticipated results into the hands of those who can put them to work.

Transitions are rarely simple and can follow different paths. In fact, the successful transition of a technology to a military, commercial or other entity is, in itself, still but an intermediary step to the final goal of revolutionary impact, which can be a years-long process. DARPA pursues and catalyzes a wide range of transition pathways, each selected to maximize the ultimate impact of a given technology.

In some cases, a DARPA program that demonstrates a military systems capability will become a program of record in one or more of the Services. In other cases, new DARPA-enabled technologies will transition first to the civilian sector, where commercial forces and private capital may drive further advances and cost efficiencies that can facilitate incorporation into military systems. In still other cases, DARPA's role ends after proving at a fundamental level the potential for a new capability, after which a military or civilian organization will typically pick it up for further research and development.

Because DARPA focuses explicitly on game-changing, non-incremental goals, some DARPA efforts do not transition upon their conclusion—either because the technology itself failed or because the resulting capability promises to be so disruptive that, in the short term at least, it cannot be integrated into existing systems or strategies. In those cases, years may pass before a DARPA-supported advance gets the opportunity to make its mark, after related technologies mature or other contexts evolve in ways that make the advance more practicable.

In recognition of the essential importance of technology transition as well as the complexity and challenges inherent in transitions, DARPA has a support office—the Adaptive Execution Office—dedicated to transition alone. Staffed by a team of individuals with deep experience in the military Services and working in close collaboration with Service liaisons, the office is committed to finding and facilitating the most effective path from the research laboratory to operational impact for DARPA-supported technologies.

Notwithstanding the many inherent challenges to successful transition, DARPA success stories can be found inside countless military and civilian devices today. Examples of programs that have made recent important transition progress include:

IN THE INFORMATION DOMAIN

Gathering and Sharing Critical Information

Extending DARPA's longstanding commitment to provide the Services with the best available technologies for ISR, DARPA has signed a technology transfer agreement with the Joint Special Operations Command (JSOC) allowing the Command to receive and operate the Autonomous Real-time Ground Ubiquitous Surveillance-Imaging System (ARGUS-IS). This very-wide-area, high-resolution motion video sensor is enabled by advanced on-board processing and an integrated ground station that allows interactive designation and tracking of multiple targets simultaneously. This technology will provide warfighters unprecedented ability to see, understand and engage hostile networks and high-value targets. The JSOC is integrating this package onto a manned platform for further development to enable near-term combat deployment.

Breaking Through the Language Barrier

Multiple DARPA language translation devices and systems have been deployed in conflict zones over the past decade, and technology improvements continue to advance national security by supporting warfighter interactions with local populations and generating regional intelligence from broadcast media and other sources. DARPA-supported development in this domain is also helping to combat transnational crime and piracy while enabling international cooperation, including humanitarian assistance.

Exploiting Photo and Video Images

Burgeoning volumes of images collected in support of surveillance and reconnaissance efforts—such as photo and video albums stored on laptop computers confiscated from insurgents during DoD operations—are growing at such a rate that unassisted analysis cannot keep up with demand for interpretation. DARPA has developed and transitioned to relevant agencies several technologies that are enhancing analysts' productivity, including technology that searches imagery and video archives for persons, objects, events and activities of interest; novel interfaces to support live video exploitation; and the capability to track all movers in a dynamic field of view.

ACROSS THE ELECTROMAGNETIC SPECTRUM

Riding the Gallium Nitride Wave

For years, DARPA and its Service partners pursued the technically daunting task of developing high-power-density, wide-band-gap semiconductor components in the recognition that, whatever the end-state task, U.S. forces would need electronics that could operate and engage at increasing range. The result was a series of fundamental advances involving gallium-nitride-enabled arrays, which now are providing significant benefits in a wide range of applications in the national security domain. Today, three major systems are under development that are enabled by DARPA's advances in RF component technology: Next Generation Jammer, designed to give the Navy the ability to jam adversary radars to protect U.S. assets; Air and Missile Defense Radar, which is designed to search for and track ballistic missiles and provide terminal illumination of targets; and Space Fence, to boost space domain awareness by providing vastly improved detection of small objects in orbit.

ON LAND

Integrating Intelligence

Military intelligence analysts face the monumental and escalating task of deriving meaning from massive volumes of complex data collected from multiple, diverse sources, including physical sensors, human contacts and contextual databases. With manual methods inadequate for this growing task, DARPA initiated its Insight program to develop new tools and automation that enhance analyst capabilities and performance and augment analysts' support of time-sensitive operations on the battlefield. The system's open, standards-based, plug-and-play architecture enables rapid integration of existing and nascent intelligence, surveillance and reconnaissance technologies and sources and an intuitive, multi-user interface designed to enhance understanding, collaboration and timely decision making. Insight is being transitioned to the Army to form the basis of the fusion capabilities for the future version of the Distributed Common Ground System-Army, the Army's intelligence program of record. This will provide Army analysts the ability to create a fused picture from a diverse set of inputs, and identify threat behavior patterns and courses of action based on that fused picture. Insight is also transitioning to the Air Force's National Air/Space Intelligence Center, where enhancements will be developed and prototyped to match that Center's specific needs.

Revolutionizing Close Air Support

When ground forces have identified the location of an adversary out of their reach, or are pinned down and in need of support from the air, they should not be dependent on paper maps and voice communications to convey essential information to pilots. Yet that has been the case, until recently. DARPA's Persistent Close Air Support (PCAS) system digitizes and greatly simplifies the mission-critical capability of air support. Today, DARPA is transitioning PCAS' air and ground technologies to Army Special Operations Command (USASOC), giving ground elements the capability to request air-delivered munitions from manned or unmanned platforms with unmatched accuracy and shared awareness. Specifically, USASOC has committed to integrate and deploy PCAS technology with its fleet of MQ-1C Gray Eagle unmanned platforms and related networking systems.

AT SEA

Delivering Long-Range Anti-Ship Capabilities

DARPA jumpstarted the development of the Long Range Anti-Ship Missile (LRASM), a precision-guided anti-ship standoff missile that is on track to reduce dependence on ISR platforms while extending range significantly. After successful flight tests in August and December 2013, the Navy has stepped up to work in close partnership with DARPA. With yet another successful test in February 2015, this time led by the Navy, the joint effort is speeding deployment of this system to deliver its unprecedented capabilities for the warfighter.

Creating Deep-Ocean "Satellites"

DARPA's Distributed Agile Submarine Hunting (DASH) program is creating fixed and mobile underwater observing systems that look up from the ocean floor. Just as satellites provide a wide-area view of the ground from space, these systems can see submarine threats passing overhead across vast volumes of ocean. This deep-ocean system has as a goal the ability to track a submarine until other platforms can arrive to track, trail or prosecute the threat. DARPA is working with the Navy to conduct at-sea prototype testing that will integrate these new capabilities with existing undersea surveillance operations—testing that will underpin Navy consideration of a potential program of record for undersea surveillance.

Expanding Marine Platforms for Unmanned Aerial Vehicles (UAVs)

Many UAVs used by the military require either an aircraft carrier or a land base with a long runway for take-off and landing—requirements that entail degrees of financial, diplomatic, and security commitments incompatible with rapid response. DARPA's Tactically Exploited Reconnaissance Node (Tern) program envisions using smaller ships as mobile launch and recovery sites for medium-altitude, long-endurance fixed-wing UAVs. To build on the early work performed by DARPA, the Navy is teaming with DARPA to enable a full-scale, at-sea demonstration of prototypes.

IN THE AIR

Gathering High-Altitude, High-Resolution Data

DARPA's High-Altitude LIDAR Operations Experiment (HALOE) provided forces in Afghanistan with unprecedented access to high-resolution 3D data, collecting data orders-of-magnitude faster and from much longer ranges than conventional methods. The Army continues to operate the HALOE sensor, collecting high-resolution terrain data for intelligence and operational use by U.S. forces. DoD is investigating program options to capture the technological breakthroughs demonstrated by HALOE over the last four years in support of critical operations.

Reconfiguring Flight Formations

Inspired by the energy efficiencies enjoyed by flocks of migratory birds that fly in a "V" formation, DARPA developed a creative way to reduce drag and fuel use for the U.S. Air Force's C-17 fleet—the largest single DoD user of aviation fuel. New DARPA software innovatively enabled precise auto-pilot and auto-throttle operations with existing C-17 hardware. Flight test results showed that these aircrew- and aircraft-friendly software changes provided a 10-percent fuel flow reduction, leading the USAF to approve a plan for transitioning the technology to the C-17 fleet in 2014. The Air Force Research Laboratory is now investigating extending the technology to other aircraft.

Advancing Fuel Cells for Longer Flights

One of the prime challenges of UAV design—and a reason these versatile vehicles have not been more broadly used in national-security-relevant missions—is how to provide power sufficient to operate a growing array of onboard systems without compromising aeronautical capabilities by the addition of burdensome battery weight. DARPA addressed this quandary by making pivotal investments in novel materials for portable fuel cells. The materials science technologies that DARPA pursued challenged conventional wisdom but ultimately paved the way for a number of firsts in fuel-cell technology development. Today this technology has evolved to the point where it is being commercialized and used to provide greater endurance for UAVs that help protect military personnel and serve other agencies. Users include the Marine Corps Warfighting Laboratory, the Army Research Laboratory and the National Park Service, with additional transitions in the works.

IN SPACE

Avoiding Collisions on Orbit

With the risk of space collisions growing apace with satellite traffic—and with satellites ever more important for communication, Earth observation and other critical civilian and military functions—space domain awareness is a high priority. DARPA's Space Surveillance Telescope (SST) promises to enable much faster discovery and tracking of previously unseen, hard-to-find objects in geosynchronous orbits, about 22,000 miles above the surface of the Earth. Development of the SST began in 2002, when engineers incorporated breakthrough technologies to achieve precision production of extremely steep aspherical mirrors mounted on a remarkably nimble foundational turret. Together, these and other novel features provide orders-of-magnitude improvements in field of view and scanning capability for deep-space surveillance. SST completed its DARPA test and evaluation period in 2012, after which the Agency worked directly with Air Force Space Command (AFSPC) to conduct a military utility assessment study. AFSPC is now poised to take ownership of the SST and has announced plans to operate it in Australia jointly with the Australian government. From its new home, the SST will feed captured information into the Space Surveillance Network, a U.S. Air Force system charged with observing and cataloging space objects to identify potential near-term collisions with orbital assets. The SST will also continue to provide NASA and the scientific community with surveillance data on transient events such as supernovae, as well as potentially hazardous near-Earth asteroids.

FOR WARFIGHTERS AND VETERANS

Revolutionizing Prosthetics

Improvements in upper-limb prosthetic technology have trailed far behind lower-limb technology advances, reflecting the medical and engineering challenges posed by the complexities of the human arm and hand. In 2014, capping an intensive, multi-year effort by DARPA's Revolutionizing Prosthetics program, the U.S. Food and Drug Administration gave marketing approval for a DARPA-developed modular prosthetic arm and hand that provides unprecedented user dexterity. Users can once again perform everyday activities such as feeding themselves, shaking hands and offering a child a pat on the back or a hug.

CHANGING WHAT'S POSSIBLE: DARPA TECHNOLOGIES THAT HAVE SHAPED OUR WORLD

DARPA focuses every day on assuring the success of its individual programs. But the ultimate objective of DARPA's work is the achievement of major, unexpected advances in national security capabilities. DARPA's record in this regard is unrivaled. Precision-guided munitions, stealth technology, unmanned systems, advanced ISR, and infrared night vision have individually and together induced remarkable changes in how U.S. forces fight and win. At the same time, the enabling technologies behind these military capabilities—new materials, navigation and timing devices, specialized microelectronics, advanced networking and artificial intelligence, among others—helped lay a foundation for private-sector investments that extended far beyond the battlefield, to create products and services that have changed how people live and work. In a further amplification of impact, these sophisticated commercial products and services are themselves being harnessed by DARPA and other DoD agencies to advance national security and ensure military advantage.

The success stories that follow describe some of DARPA's most significant impacts. Each one describes how the Agency's investments started, how the resulting technologies moved into use and, ultimately, how these technologies advanced national security. A theme common to all of these stories is that many individuals and organizations—public and private—were involved in each success, a reflection of the importance of the Nation's larger and vibrant technology ecosystem. In every case, however, it was DARPA that made the pivotal early technology investments that make the inconceivable possible and the seemingly unattainable real.

Each person who has the privilege of serving at DARPA today strives to follow in the footsteps of those who came before them—by building new technologies that can help secure the future for the next generation. These success stories of past DARPA impact are reminders of why the people of DARPA do their work, and they inspire all of us to reach ever higher.

DARPA SUCCESS STORY: PRECISION-GUIDED MUNITIONS

THE NEED AND THE OPPORTUNITY

During the Cold War, the Soviet Union's superior tank force presented a serious conventional threat to U.S. and NATO forces in Europe. While U.S. nuclear weapons provided a crucial offset to this imbalance, military leaders recognized that precision-guided munitions (PGMs) could provide a non-nuclear offset by posing a threat of long-range U.S. surgical strikes on second-echelon enemy tanks after a Soviet invasion. Operations in Vietnam drove home the need for guided munitions, or "smart weapons," to strike targets more precisely with less collateral damage. With greater precision, munitions could be directed specifically at infrastructure targets such as bridges to isolate forces, as well as radars and integrated air defense systems, command and control centers and airfields. Moreover, if munitions could be self-guided once launched, they could be launched from a greater distance, reducing risk for pilots and aircraft.

Air Force weapons load-crew chiefs load precision-guided munitions on an A-10C in Afghanistan in 2013.

More recently, in response to growing U.S. successes with PGMs, adversaries have changed their tactics to include more use of distributed warfighters in urban settings, requiring even greater precision from U.S. munitions. Today, with battlespaces and foes increasingly dispersed and elusive, the need for PGMs is greater than ever.

THE DARPA SOLUTION

DARPA's contributions to PGMs date back to the 1960s and early 1970s, with its work on an array of technologies—including lasers, electro-optical sensors, microelectronics, data processors and radars—that would eventually become critical components of the first precision systems. In 1978, DARPA integrated a number of these efforts under its Assault Breaker program, which, over a four-year period, laid the technological foundation for several smart-weapon systems that were ultimately fielded with high success, including the Joint Surveillance Target Attack Radar System (JSTARS), which integrated PGMs with advanced ISR systems developed with DARPA support; the Global Hawk unmanned aerial vehicles; an Air Force air-to-ground missile with terminally guided submunitions; the long-range, quick-response, surface-to-surface Army Tactical Missile System, which featured all-weather, day/night capability effective against mobile and other targets; and the Brilliant Anti-armor Tank (BAT) submunition, which used acoustic sensors on its wings to detect and target tanks.

DARPA's seminal work in the 1980s to miniaturize receivers for GPS, in conjunction with DARPA-developed advances in inertial navigation, expanded the Nation's arsenal of PGMs through such innovations as "bolt-on" Joint Direct Attack Munitions (JDAM) GPS kits, which gave otherwise unguided or laser-guided munitions new, high-precision capabilities. Key to these developments were gallium arsenide chips developed through DARPA's Monolithic Microwave Integrated Circuit program, which also enabled the RF and millimeter-wave circuits needed in precision weapons.

Through its Tank Breaker program in the mid- to late-1970s, DARPA played a significant role in developing the concepts and technologies for what would eventually become the self-guided, anti-armor Javelin missile system. DARPA worked hard to include imaging infrared arrays in the Javelin's design, and in particular the two-dimensional arrays that were ultimately so successful in the missile's seeker. DARPA also funded an alternate source for focal plane arrays that proved crucial to the Javelin's success.

Other modern munitions that DARPA helped bring to fruition include the Advanced Medium-Range Air-to-Air Missile (AMRAAM), the Sensor Fuzed Weapon, and the Tube-launched and Optically tracked, Wire-guided (TOW) anti-tank missile and the Advanced Cruise Missile.

THE IMPACT

The development and use of increasingly precise guided weapons has allowed U.S. forces to attack and eliminate more difficult targets from greater distances with increasing probability of success. These capabilities were instrumental to U.S. strategy during the Cold War, in the Gulf War, and more recently as U.S. forces have had to contend with less concentrated and more elusive foes. In short, while pilots used to talk about sorties per target, the talk today is about targets per sortie.

PGM operations in Iraq and the Balkans in the 1990s, for example, demonstrated the new technologies' effectiveness in sequential, highly effective surgical strikes, primarily involving cruise missiles and laser-guided munitions. By increasing the assuredness of targeting success and minimizing the risk of American troop losses and corollary damage around targets, precision weapons offered U.S. leaders expanded foreign-policy and military options while engaged in these conflicts.

In Iraq in particular, DARPA-enabled PGM capabilities—including the Javelin, making its combat debut—proved pivotal. Early in that conflict, precision strikes disabled Iraq's integrated air defense systems as well as enemy ground forces and aircraft on the ground. And throughout the campaign, GPS enhancements such as JDAM tied directly to DARPA made a big difference in the precision and effectiveness of U.S. attacks on key, fixed targets.

Subsequent improvements and applications of DARPA-developed PGM technologies contributed significantly to U.S. superiority in Afghanistan, facilitating highly effective sorties by U.S. aircraft and close air support for ground troops.

TRANSITION

DARPA-developed PGM technologies have transitioned to the Navy, the Army, the Air Force and the Marine Corps.

WHAT'S NEXT

DARPA is collaborating with the Office of Naval Research to accelerate development and deployment of the Long-Range Anti-Ship Missile (LRASM), a precision-guided anti-ship missile designed to address the growing need to be able to penetrate sophisticated enemy air defense systems from long standoffs. Based on the successful Joint Air to Surface Standoff Missile Extended Range (JASSM-ER) system, LRASM aims to reduce dependence on ISR platforms, network links and sophisticated external navigation in electronic warfare environments.

Separately, DARPA's Persistent Close Air Support program has developed modified commercial devices that allow ground-based tactical users to request and target air-delivered PGMs. The program's investment with the Navy to develop these targeting tools is proving extremely beneficial on the battlefield today, with further modifications and improvements under development.

Ordnance technicians with the Marine Expeditionary Brigade-Afghanistan mount a Joint Direct Attack Munition to an AV-8B Harrier at Kandahar Airfield.

DARPA SUCCESS STORY: STEALTH

THE NEED AND THE OPPORTUNITY

By the early 1970s, U.S. military superiority was threatened and strategic options dangerously narrowed by the introduction of advanced air-defense missile systems. These integrated defense systems included radar-guided surface-to-air missiles (SAMs) and modern fighter aircraft armed with radar-guided missiles networked with early warning, acquisition and targeting radars, coordinated by sophisticated command and control networks. After suffering significant losses against such systems in Vietnam, the United States sought a means of penetrating adversaries' integrated air defense systems and attacking those systems' key nodes, so U.S. airpower could quickly be brought to bear on well-protected enemy targets and American air dominance could be assured.

THE DARPA SOLUTION

DARPA pursued several developmental strategies and technologies in combination to make reduced radar detectability a reality for otherwise vulnerable U.S. aircraft deployed against enemy targets. As an initial consolidated product of this effort in the mid-1970s, DARPA developed and demonstrated Have Blue, the world's first practical combat stealth air vehicle, which benefited from new design concepts, new radar cross section prediction tools, new materials and eventually new tactics. Have Blue led directly to the Air Force's procurement of the F-117 stealth fighter.

In the mid-to-late 1970s and early 1980s, DARPA developed and demonstrated the first radar-equipped stealth air vehicle, Tacit Blue. This vehicle demonstrated the ability to operate radar and maintain sufficiently low radar cross-section in the threat frequencies to enable its pursuit of high-value targets. This program laid the foundation for the Air Force's B-2 stealth bomber.

Among the key low-observability technologies developed by DARPA were curved surfaces designed to reduce radar cross-section, radar absorbent materials, infrared shielding, heat dissipation, reduced visual signatures, low-probability-of-intercept radar, inlet shielding, exhaust cooling and shaping, windshield coatings and computing capabilities.

THE IMPACT

Equipped with stealth designs and technologies, U.S. forces quickly overcame opposing forces' air defenses and destroyed key targets in Iraq (Desert Storm in 1991 and Operation Iraqi Freedom in 2003), Afghanistan (Operation Enduring Freedom in 2001) and Libya (in 2011), definitively changing the shape and prospects of those wars. Stealth's key contributions to success in these missions were complemented by and dependent upon DoD's use of other technologies, including DARPA-enabled precision guided munitions deployed by stealth and non-stealth aircraft that could strike targets

DARPA developed Have Blue, the world's first practical combat stealth air vehicle, which led directly to the Air Force's procurement of the F-117 stealth fighter.

more accurately and achieve success while minimizing collateral damage. Today, despite heavy investments in sophisticated networked air defense systems, U.S. adversaries have very limited ways to defend against nighttime air attacks by American stealth forces.

Signature management across the RF spectrum has become an important design feature for several generations of USAF combat aircraft (including the F-117, B-2, F-22 and F-35) and has become a major focus of industry research and development. Stealth technologies also have been applied to a wide range of weapon systems and military platforms, including missiles, helicopters, ground vehicles and ships, including the experimental Sea Shadow stealth ship and the Navy's DDG 1000 destroyer.

TRANSITION

DARPA-developed stealth technology has transitioned to the Air Force for use in several fighters and bombers. In both Have Blue and Tacit Blue, DARPA worked closely with the Air Force acquisition and operational community and performers–notably Lockheed Corporation and Northrop Corporation–to enable them to quickly move concepts into production.

A B-2 stealth bomber flies over Colorado in 2012.

WHAT'S NEXT

Adversaries now strive to take away the U.S. stealth advantage by layering integrated air defense systems in depth and by exploiting other supposed vulnerabilities. DARPA continues to explore breakthrough technologies with the potential to extend and expand the U.S. arsenal's capacity for initiating strategic surprise.

DARPA SUCCESS STORY: UNMANNED AERIAL VEHICLES (UAVS)

THE NEED AND THE OPPORTUNITY

Whether the mission is intelligence, surveillance and reconnaissance (ISR), battle damage assessment, ground or maritime force support, or aerial strikes, the air domain is essential to national security. But flight is inherently risky, and flight in contested environments is riskier still. Thus the DoD has for decades sought access to ever more capable unmanned aerial vehicles (UAVs) to augment its airborne assets.

Technological advances have gradually expanded the UAV mission portfolio and the range of tactical conditions under which UAVs can operate. Even as UAV system capabilities have grown, however, strategic demands on these assets have continued to increase. Today there remains a pressing need for UAV systems that are more reliable than current ones; have greater range, payload and endurance; feature improved communication links capable of operating in contested environments; and are capable of more tactical combat missions in support of a system-of-systems architecture.

THE DARPA SOLUTION

DARPA has invested in UAV development since the 1960s, a time when the concept of using UAVs engendered widespread skepticism within military circles. The agency's foresight and unflagging interest in UAVs, which included research on structures, propulsion, guidance, sensors, communications and autonomy, helped fuel a revolution in unmanned aircraft that continues to this day.

In 1962, DARPA pioneered early unmanned vertical take-off and landing (VTOL) technology, partnering with the U.S. Navy to develop the QH-50 Drone Anti-Submarine Helicopter (DASH). This platform could carry antisubmarine torpedoes and gave destroyers the ability to attack enemy submarines far beyond the range of their antisubmarine rockets. Later, DASH was equipped with television cameras for ISR purposes in Vietnam, where U.S. forces gave it the affectionate nickname "Snoopy."

In the 1970s, DARPA initiated project Teal Rain, focused on improving unmanned aircraft engine performance and design, and its Praeire and Calere programs, which demonstrated the ability to carry significant payloads for operationally required durations. At the same time, DARPA began work on the first small, low-observable, remotely piloted vehicle (RPV) for the Navy. And later that decade, DARPA funded the development of small, airborne sensor technologies for use in UAVs, including miniaturized stabilization systems, moving target indicators, radars and anti-jam data links—all of which contributed to increased platform survivability at greater ranges.

In the 1980s, DARPA support led to the development of the Amber long-endurance UAV, elements of which were later incorporated into the Gnat and MQ-1 Predator, which in turn led to the development of the MQ-9 Reaper ISR and strike platform. Also during this period, DARPA investments supported the CONDOR flight test program, which demonstrated enhanced UAV ISR capabilities.

DARPA's research in the 1980s into long-endurance UAVs led to the development of the MQ-9 Reaper ISR and strike platform.

In the 1990s, DARPA sponsored development of the RQ-4 Global Hawk, the world's first and only successful operational high-altitude long-endurance ISR UAV, used extensively in Iraq, Afghanistan and other operational areas around the world. In 1996 DARPA launched its Micro Air Vehicle (MAV) program, which focused on smaller unmanned airborne systems designed to scout local terrain. One of the many outcomes of this effort was the T-Hawk UAV, a VTOL ducted fan with a 13-inch diameter, equipped with video cameras and infrared sensors and used to search for roadside bombs in Iraq and other ISR missions.

Another product of DARPA's MAV program was the Wasp, which features a fixed wingspan of only 16 inches, weighs less than one pound, and can fly for one hour at 20 to 40 miles per hour. Fitting in a backpack and easily launched by hand, Wasp's quiet propulsion system has enabled squad-level, on-demand, real-time reconnaissance of both open and urban environments.

In the early 2000s, DARPA initiated a demonstration Unmanned Combat Air Vehicle program to advance cooperative mission planning, vehicle autonomy and manned-unmanned teaming concepts of operation. With input from the Navy and Air Force, this program evolved into the Joint Unmanned Combat Air Systems program, which in turn led to production of the Navy's X-47B unmanned combat air vehicle demonstrators for carrier operations, which have completed a number of firsts aboard U.S. aircraft carriers.

In 2005, DARPA pushed the UAV envelope again under its Nano Air Vehicle program by developing flapping-wing-based hovering systems with a hummingbird-like appearance for indoor and outdoor ISR missions. Featuring wingspans of just six inches and weighing under an ounce, these systems demonstrated the first-ever controlled hovering and fast forward flight of any air vehicle system carrying its own energy source and using only flapping wings for propulsion and control.

During this same period, DARPA paved the way for extended-range unmanned VTOL operations by sponsoring development of another "Hummingbird": the A-160, a long-endurance, high-speed unmanned helicopter that flew for 18.7 hours and set a world UAV record for endurance in its weight class.

THE IMPACT

DARPA's unmanned aircraft innovations and technology transitions have revolutionized ISR missions, ensuring not only air dominance for the DoD but also information dominance for the DoD and other agencies. As a direct result of DARPA's efforts, UAVs outfitted with ISR payloads can operate today for longer periods at higher altitudes than ever before—while gathering unprecedented amounts of data and providing high-resolution imagery for worldwide operations. At the same time, DARPA-developed technologies have made it easier for UAV operators to use these important battlefield assets. For example, the sophisticated GPS and micro-miniaturized autopilot functions in the Wasp enabled, for the first time, a very small airplane to fly itself so its operator could focus on the mission and the gathering of necessary tactical imagery. In 2008, Wasp became the first micro air vehicle adopted by the U.S. Armed Forces in support of a program of record.

UAVs provide an excellent example of how a sustained thematic effort by DARPA can support multiple generations of unique technological advances, each leading to its own new capabilities and opportunity for transition. From the early UAVs over Vietnam; to the more sophisticated unmanned aircraft that provided intelligence and targeting information on Bosnian artillery locations in support of the United Nations peacekeeping mission there in the 1990s; to the more recent ISR, targeting, strike and damage-assessment missions in Afghanistan and Iraq, DARPA-developed UAV technologies have proven essential to U.S. military effectiveness and national security.

UAVs have also become the focus of enormous entrepreneurial creativity and investment outside the DoD, which has fueled civilian commercial markets. In fact, UAVs today represent the fastest growing segment of the aerospace industry, a tribute to

A Navy X-47B unmanned combat air vehicle demonstrator performs carrier operations.

DARPA's legacy investments. In addition to law enforcement and public safety agencies, companies are developing concepts and plans for UAVs to contribute to power line monitoring, crop assessments, wildfire spotting, mining, logging and the provision of remote communications links—not to mention early adoption by Hollywood and related entertainment industries.

TRANSITION

DARPA UAVs and UAV-related technologies have transitioned to the Air Force, the Navy and the Army and, as described above, have become essential DoD tools.

WHAT'S NEXT

Military and national security needs are expected to demand more, and more varied, UAV capabilities, and as UAVs continue to proliferate, technologies will be required to manage their missions. A number of current DARPA programs have the potential to expand the performance capabilities of UAVs, including programs that aim to develop technologies relating to air-breathing and non-air-breathing propulsion concepts, advanced rotor innovations, thermal management, guidance, navigation, flight controls, sensors and advanced payloads. Other DARPA programs are addressing need for better management and processing of the huge amounts of data that are being collected by, and are required by, UAVs and related ISR platforms.

DARPA is also addressing the fact that, today, most unmanned aircraft require either land bases with long runways or aircraft carriers to enable take-off and landing—requirements that impose substantial financial, diplomatic, and security commitments that can be incompatible with a rapid-response capability. The Tactically Exploited Reconnaissance Node (Tern) program, a joint DARPA-Navy endeavor, envisions using smaller ships as mobile launch and recovery sites for medium-altitude long-endurance fixed-wing UAVs, even in turbulent seas.

DARPA also envisions eliminating crew risk for delivery missions in dangerous and challenging terrain through its Aerial Reconfigurable Embedded System (ARES) program, which foresees development of an unmanned VTOL craft that can pick up, deliver and drop off modular payloads such as sensor packages, critical supplies and combat equipment.

DARPA SUCCESS STORY: TECHNOLOGY FOR INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE

THE NEED AND THE OPPORTUNITY

The ability to know what the adversary is up to, and to identify targets anywhere, any time, and under any conditions, is vital to national security and is achieved in large part by a suite of activities commonly known as intelligence, surveillance and reconnaissance (ISR). During the Cold War era, the need for ISR dominance was rooted in a tactical imbalance: Soviet forces had a significant quantitative advantage in artillery, armor, and manpower over U.S. and North Atlantic Treaty Organization forces. Superior ISR offered the United States and its allies a means of counterbalancing this asymmetry. In the decades since the fall of the Soviet Union, the need for sophisticated ISR technologies only increased—to mitigate threats from other nation states and to compensate for the tactical

An E-8C Joint Surveillance Target Attack Radar System (JSTARS) flies over Edwards Air Force Base, California, in 2009.

advantages enjoyed by a growing cadre of non-state insurgents and terrorist groups, including the ability to hide in civilian populations.

THE DARPA SOLUTION

Over a period of decades dating back to the Cold War, DARPA developed a series of ever more advanced technologies to help ensure that U.S. ISR would be the best in the world. In the 1970s, for example, to help counter the Soviet threat, DARPA launched its Pave Mover target-acquisition weapon-delivery radar program, through which it developed a moving-target-indication radar that could discriminate slowly moving targets from background signals. In 1978, DARPA integrated Pave Mover and related technologies in the Assault Breaker program, which enabled U.S. long-range strike assets to attack armor deep in enemy territory using DARPA-developed airborne reconnaissance and guidance technologies, including cutting-edge electro-optical sensors in addition to the advanced radar systems themselves, and data links enabling these systems to work in concert.

Some of these technologies were later improved and incorporated in more modern systems and platforms, including, in the 1980s, the JSTARS, an Air Force battle management and command and control aircraft that can track ground vehicles and relay images to theater commanders. More recently, the Vehicle and Dismount Exploitation Radar (VADER) pod has been used to track not only vehicles but also dismounted personnel.

To extract greater military value from the radars developed under Assault Breaker, as well as from more advanced tactical radars, DARPA launched three initiatives: the Moving Target Exploitation, Affordable Moving Surface Target Engagement and NetTrack programs. These efforts produced software tools able to guide high-precision munitions and identify subtle patterns of activity over very wide areas, including those of low-profile threats such as mobile missiles.

DARPA's more recent contributions in advanced sensor and radar technology have made it possible to detect small targets, such as armored vehicles, even when visual conditions are degraded (as by bad weather) or denied (as by camouflage or other evasive techniques). DARPA's Jigsaw program, for example, developed a 3-D imaging laser radar able to detect vehicles masked by camouflage or foliage. And DARPA's foliage-penetrating reconnaissance, surveillance, tracking and engagement radar enabled unprecedented detection of targets concealed by obstacles. Another DARPA program, Discoverer II, was initiated in the late 1990s to establish a constellation of space radar systems endowed with Pave Mover capabilities and resulted in the deployment of advanced ISR components on orbit.

Most recently, DARPA developed its Autonomous Real-Time Ground Ubiquitous Surveillance Imaging System (ARGUS-IS), a high-performance, real-time ground-moving-object tracker widely recognized as the premier airborne imaging sensor in the world today.

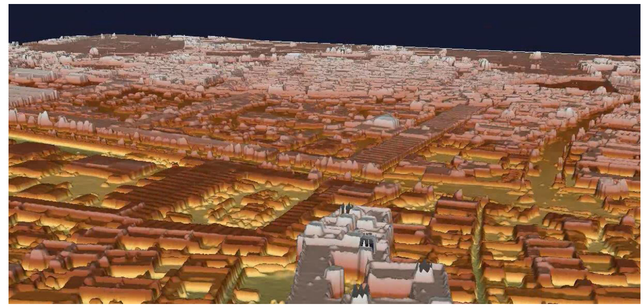
THE IMPACT

DARPA's contributions to U.S. ISR efforts have had an enormous impact on military operations, enabling operational concepts not previously possible and providing a force-multiplying effect for U.S. troops.

In Operation Desert Storm, DARPA-enabled airborne ISR systems such as JSTARS provided critical tactical intelligence to U.S. warfighters and helped minimize collateral damage. DARPA-developed systems also provided real-time tactical views of the battlefield in unprecedented detail in Operation Iraqi Freedom. JSTARS identified direction and speed of military ground vehicles and helicopters and conveyed those findings through secure data links with Air Force command posts, Army mobile ground stations, and military analysis centers distant from battle zones, while DARPA-developed radar and wide-area video technologies led to the discovery of terrorist and insurgent networks.

DARPA's ARGUS system was deployed in Operation Enduring Freedom (OEF), along with DARPA's High-Altitude LIDAR Operational Experiment (HALOE), which provided forces in Afghanistan with high-resolution 3-D data collected at rates orders of magnitude faster and from much longer ranges than conventional methods. HALOE and VADER were part of the DARPA Forward Cell, recognized with a Joint Meritorious Unit Award in 2012 for providing unique intelligence and other support for OEF.

Many of these capabilities have been applied in conjunction with unmanned aerial vehicles, which in themselves have contributed enormously to U.S. ISR efforts and were developed with critical contributions from DARPA. UAVs have served as platforms for DARPA-developed ISR technologies, and have themselves been guided through challenging environments via airborne and ground-based ISR assets.



In support of U.S. forces in Afghanistan, High-Altitude LIDAR Operational Experiment (HALOE) provided unprecedented access to high-resolution 3D data and collected imagery orders of magnitude faster and from much longer ranges than conventional methods.

TRANSITION

DARPA ISR technologies have transitioned to and are in use by the U.S. Air Force, U.S. Navy, U.S. Army, National Reconnaissance Office, National Geospatial-Intelligence Agency, Central Intelligence Agency and Joint Improvised Explosive Device Defeat Organization, among other entities.

DARPA's ISR technologies have found application in a number of critical civilian systems as well. The technologies for phased array radar systems originally developed for military ISR now support cellular communications. Advanced radar signal processing techniques developed in part by DARPA for ISR are now used in civilian air traffic control systems and have increased the accuracy of airspace management. And solid state detectors and high-speed electro-optical sensors derived from DARPA programs now are prevalent in cellphone cameras and have revolutionized photography and video for the commercial world.

WHAT'S NEXT

Today DARPA is developing new technological capabilities to enhance the provision of ISR in contested environments. And because advanced ISR systems are now generating data at rates beyond what humans can assimilate, understand and act upon, DARPA is developing new processing technologies to fuse data from multiple sensors observing multiple objects, and to automate the detection of objects and activities of interest. The Agency also aims to identify threats using advanced pattern analysis, discovery and prediction algorithms, which hold the promise of offering enhanced support for time-sensitive operations.

DARPA SUCCESS STORY: INFRARED NIGHT VISION TECHNOLOGY

THE NEED AND THE OPPORTUNITY

From time immemorial, the cover of darkness has challenged aggressors and hobbled defenders, inspiring a range of helpful but imperfect solutions—from low-tech illuminating flares to sophisticated image-intensification goggles that amplify minuscule remnants of ambient light. Night vision technologies saw considerable improvement during and after World War II, and work conducted by the U.S. Army Night Vision Laboratory (NVL) on image-intensifier tubes helped significantly as recently as the Gulf War, both for ISR missions and for nighttime air and ground targeting. Over the years, however, even advanced technologies have found their way quickly to commercial markets and hence to the full range of U.S. adversaries. An ongoing U.S. advanced R&D effort allows U.S. forces to maintain the vital competitive advantage that accrues to those who best own the night.

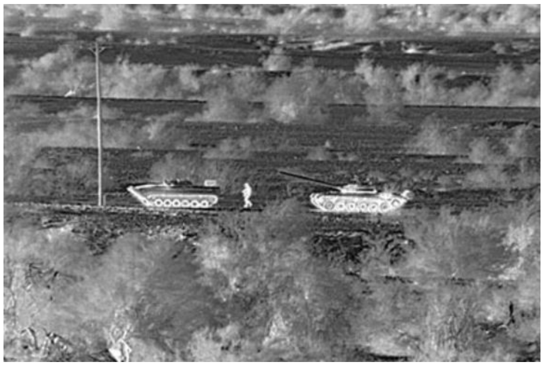
THE DARPA SOLUTION

While other research entities have focused on image intensifiers that amplify small amounts of visible light, such as starlight, DARPA's investments have focused primarily on thermal imaging, which enables vision under no-light conditions by detecting thermal wavelengths in or near the infrared range. Highly heat-sensitive imagers can detect adversaries who are in camouflage during the day or night, and can determine not just the presence of a vehicle but whether it has been operated recently by detecting residual engine heat.

Starting in the 1980s and continuing through the 1990s, for example, DARPA made significant investments in the field of cryogenically cooled, very-high-performance infrared imagers, which use chilled sensors to suppress background electromagnetic noise and increase sensitivity to low-energy signals. In particular, DARPA's Flexible Manufacturing program, which began in the early 1990s, paved the way for the use of mercury cadmium telluride (HgCdTe) for imaging purposes, now the most common compound material in focal-plane-array devices for high-performance cooled systems.

Over the same period, DARPA made significant advances in uncooled technologies using very small radiant heat sensors to detect infrared radiation

As seen with a light-amplification night vision device, a Soldier looks through the thermal night sights of the Tube-launched, Optically tracked, Wireguided (TOW) system to observe the Kosovo-Macedonia border in 2001.



DARPA developed thermal imaging turns an otherwise totally dark scene at standoff distance into "daylight."

from potential targets. While uncooled systems can't match the sensitivity of cooled devices, they have big advantages in terms of weight and cost. DARPA's Low Cost Thermal Imager—Manufacturing (LCTI-M) program furthered these advantages, demonstrating innovation in very-low-cost manufacturing and leading to uncooled small arrays that yielded improvements in size, weight, power requirements and cost. Among other achievements, DARPA's work on uncooled thermal systems, in concert with the work conducted by the NVL and the Services, resulted in the microbolometer infrared sensing technology that is now widely used by the U.S. military.

Recent DARPA investments in a previously underexploited spectral band—short-wave infrared, which uses skyglow with or without starlight or moonlight—has also proven to boost night vision capabilities and is anticipated to help maintain tactical advantage over adversaries.

THE IMPACT

In concert with advances made by the Services, DARPA's work has helped U.S. warfighters operate and dominate at night by delivering such products as night driving aids, thermal weapon sights and tank sights for vehicles. Moreover, DARPA's research has catalyzed dramatic reductions in pixel sizes and, consequently, in device size, weight, power needs and cost. Expensive and cumbersome systems that could only be mounted on large platforms like aircraft, tanks and ships are now becoming affordably available as head- or rifle-mounted devices and other Army and Marine Corps dismount systems. In particular, DARPA-enabled infrared night vision capabilities are set to be incorporated in handheld- and rifle-scopes through the U.S. Army PEO Soldier Thermal Weapon Sight and Enhanced Night Vision Goggle programs.

TRANSITION

Working closely with the DoD's Night Vision and Electronic Sensors Directorate, which coordinates the Department's work on night vision, DARPA has transitioned or is now transitioning several night vision-related DARPA programs to a range of U.S. military offices, including the Army Research Laboratory, Army Space and Missile Defense Command, Air Force Research Laboratories, Air Force Special Operations Command, Naval Research Laboratory, Office of Naval Research and Marine Corps Systems Command. Applications include clip-on thermal sights for surveillance and targeting by snipers, surveillance applications on ships, and technologies to aid helicopters when landing in brownout conditions. Newly developed short-wave infrared technology is also being embraced by all three Services and is in transition for a variety of multi-sensor imaging applications on airborne, ground and maritime platforms.

DARPA-supported research on uncooled thermal techniques are also increasingly penetrating the commercial marketplace in various roles, including for security and law enforcement, medicine and firefighting, recreational sports, enhanced vision for drivers, production and power system monitoring and assessment of thermal insulation for energy conservation. With these beneficial applications comes wider geographic availability of this advanced technology, underscoring the reality that even sophisticated products offer only temporary advantages.

WHAT'S NEXT

Increasing availability of low-cost night vision capabilities has reduced the U.S. competitive advantage and created an imperative for domestic development of more advanced systems. In particular, there is a need to see at night with greater clarity than is possible today, at greater distances, under zero-light conditions and with equipment that is lightweight and lower cost. U.S. forces also need to more fully conquer vision challenges during brownouts, bad weather and other sight-obscuring conditions, and be able to share information from night vision devices among warfighters in real time. There is also a need to combine into a single, multi-band system the varied capabilities now found in different imaging devices, so troops would have less to carry.

DARPA SUCCESS STORY: THE BIRTH AND MATURATION OF THE GLOBAL POSITIONING SYSTEM

THE NEED AND THE OPPORTUNITY (PART 1)

The launch of Sputnik in 1957 led not only to the creation of DARPA but also, thanks to a serendipitous observation, to the development of the world's first satellite-based navigation system. U.S. scientists tracking the Soviet orb via the radio signal it steadily transmitted noted the Doppler effect's influence on that signal's frequency. That observation led to the realization that mobile assets on land or at sea might be able to keep track of their location by measuring the Doppler shifts of signals transmitted from space.

THE DARPA SOLUTION

To operationalize the idea of using Doppler shifts to provide real-time position information, DARPA and the Navy provided seminal funding in the late 1950s and early 1960s to build and launch into orbit the TRANSIT system—a constellation of high-flying satellites linked to computers aboard submarines, providing rudimentary, satellite-based geolocation. A separate, follow-on orbital constellation program, NAVSTAR, launched in the 1970s, went further by having an array of satellites designed and built by the Naval Research Laboratory transmit signals synchronized with the use of onboard clocks. These systems provided submarine operators with increasingly accurate determinations of their location at periscope depth, allowing targeted ballistic missile launches from under the surface.

THE IMPACT

GPS was a revolutionary innovation for the attack submarine world, allowing submarines to minimize

An Army platoon leader checks his location with a handheld GPS device while on patrol in southern Afghanistan in 2012.

time spent on the surface or with the periscope extended and enhancing the deterrence value of the fleet.

THE NEED AND THE OPPORTUNITY (PART 2)

By the late 1970s, even with the powerful NAVSTAR system in place, demand for wider access to GPS was growing fast within the military. But GPS receivers—primarily furniture-sized equipment, with even the smallest versions being 50-pound manpacks—remained bulky and demanded substantial power supplies, limiting their mobility and usefulness.

THE DARPA SOLUTION

In the 1980s, DARPA launched its Miniature GPS Receiver (MGR) program—often referred to as the "Virginia Slims" program—to shrink the size, weight and power requirements of GPS receivers. DARPA incorporated advances in chip design to develop a revolutionary, fully digital, lightweight, battery-operated GPS receiver the size of a cigarette pack. The program succeeded and was completed in 1991.

THE IMPACT

The widespread deployment of miniaturized GPS units has transformed military operations with its near-ubiquitous provision of precise time and location data. GPS today not only assures precision launches but can also guide munitions in flight. And GPS-based timing synchronization has enabled more secure communications systems for troops in the field.

TRANSITION

Mobile GPS technology transitioned to the U.S. Navy, U.S. Air Force, U.S. Army and the DoD Global Positioning Systems Directorate, among other components of the Defense Department, as well as to other government agencies and commercial outlets. Today GPS supports work in a wide range of critical U.S. economic sectors, including transportation, weather prediction, resource management and agriculture. And as every owner of a smartphone knows, it supports a booming, global e-commerce network that is tailored to users' precise location.

WHAT'S NEXT

GPS has provided a tremendous strategic advantage to the U.S. military, but heavy reliance on GPS has also become a strategic vulnerability. The need to be able to operate effectively in areas where GPS is inaccessible, unreliable or potentially denied by adversaries has created a demand for alternative precision timing and navigation capabilities.

To address this need, DARPA is investing in radically new technologies that have the potential to deliver GPS-quality position, navigation and timing information for military systems, including novel inertial measurement devices that use cold-atom interferometry; chip-scale self-calibrating gyroscopes, accelerometers and clocks; and pulsed-laser-enabled atomic clocks and microwave sources.

A U.S. Army infantryman uses a Defense Advanced GPS Receiver (DAGR) to document his position during a dismounted patrol in Afghanistan in 2010.

DARPA SUCCESS STORY: A TECHNOLOGY FOUNDATION FOR PERSONAL ELECTRONICS

THE NEED AND THE OPPORTUNITY

Decades before smartphones and tablets became ubiquitous, DARPA was researching networking, communications, high-performance computing, graphical user interfaces, artificial intelligence, advanced microelectronics, novel materials and position, navigation and timing—the technologies that, taken together, laid critical foundations for modern personal electronics. Today, many feel they could hardly live without their mobile devices. For warfighters that sense is more than metaphorical, as these devices are becoming not just communications devices but combat tools and literal life-savers.

THE DARPA SOLUTION

Spanning several decades, DARPA aggressively pursued and successfully developed new ways to process, analyze and display information; increase the speed and capabilities of electronic devices; and reduce the size, weight, power and cost of these devices. Much of this path-breaking research led to substantial additional federal investments. The technologies that emerged now underpin modern military capabilities from ISR to command and control to electronic warfare. Many of the technologies also opened the door to vast commercial market opportunities, leading private companies, entrepreneurs and investors to build new businesses and new industries in electronics, software, communications and computing. Together these public and private investments created the conditions for the design and production of a slim, engaging device to surf the web, map a journey, check in on social media—and even make an old-fashioned phone call.

Important DARPA-funded innovations that helped lay the foundation for mobile devices include:

- The Internet
- Graphical user interfaces that allow users to interact readily with their devices
- Artificial intelligence and speech recognition technologies
- RF power amplifiers that transmit RF signals to cell towers
- Software-defined radio advances, which led to the multi-protocol, multi-band RF devices used in all cellular devices, making it possible to roam on many networks using one device
- Chip-scale high-performance accelerometers and gyroscopes based on microelectromechanical systems (MEMS) and miniaturized GPS receivers that underlie smartphone orientation and navigation capabilities
- Computer-aided-design tools and 193-nm photolithographic technologies, which enabled the design and production of state-of-the-art silicon chips for memory and processor functions
- Early work on rechargeable lithium ion battery technology
- High-performance polymers for advanced liquid crystal display technology

DARPA-funded technologies underpinned the development of multiple features in today's smartphones.

Maps
High Resolution Imagery with Operational Overlays

WAM
Weapons and Munitions Guide

Blackbox
Geo-Referenced Media and Review of Historical Traces

RIED
Recognition of Improvised Explosive Devices

NavTool
Share Plan & Edit Routes

Language Games
Activities for Learning Pashto and Dari Phrases

A few of the apps created for and by Soldiers in TransApps to make smartphones a valuable tool in the austere environment in theater.

THE IMPACT

By consolidating multiple sensors and components into a single system with standardized protocols and a unified interface, mobile devices have provided warfighters dramatically improved situational awareness and communications capabilities while greatly reducing the size, weight and power of the earlier systems they replaced. Perhaps even more important is the pace at which mobile devices and their seemingly endless apps continue to improve. A huge applications ecosystem has created the ability to advance functionality at a speed nearly as fast as human ingenuity. And the sheer scale of the consumer market means the devices themselves are continuously upgraded, offering unprecedented capabilities at low cost and facilitating a host of new capabilities.

DARPA's Broad Operational Language Translation (BOLT) program, for example, is using a simple mobile phone platform to support communication with non-English-speaking populations and identify important information in foreign-language sources. And the agency's Persistent Close Air Support (PCAS) program has created a tablet-based system that allows dismounted ground units and combat aircrews to share real-time situational awareness and weapons systems data, and enables ground agents to quickly and positively identify multiple targets simultaneously.

Similarly, DARPA's Transformative Applications (TransApps) program used secure Android smartphones to deliver current, high-resolution digital map imagery directly to troops in Afghanistan, along with tools to overlay new data and to allow troops to insert updates after returning from missions. Perhaps most importantly, TransApps simplified the process of creating new apps responsive to warfighters' needs, facilitating the creation of new operational tools on the fly. More than 3,000 TransApps mobile devices were deployed in Afghanistan within 18 months to support Army operations.

TRANSITION

DARPA's work on the technologies underpinning personal electronics exemplifies an indirect but important approach to advancing military capability—one in which DARPA-funded research takes root in the commercial sector, then finds application in the military. DARPA projects in a large number of universities, companies and laboratories led to an extraordinary range of technological advances that together enabled the creation of smartphones and tablets. An enormous amount of private capital and entrepreneurial drive then created massive consumer markets. Today, DARPA is showing what these commercial devices enable for military needs.

WHAT'S NEXT

While the commercial market for mobile devices is widely appreciated—over 1.5 billion were shipped in 2014—their use in military operations is just beginning. Mobile devices, with their fast pace of change in both apps and hardware, offer a unique opportunity to rethink the pace at which our forces adopt new technology.

DARPA SUCCESS STORY: ARTIFICIAL INTELLIGENCE

THE NEED AND THE OPPORTUNITY

Advances in electronics and computer technology during and following World War II provided the foundation for machines with the potential to undertake tasks traditionally associated with human intelligence. But it wasn't until 1956 that the field of artificial intelligence (AI) was effectively born, with the launch of the Dartmouth Summer Research Project on Artificial Intelligence—a month-long academic brainstorming session devoted to the topic. The Project asserted that "every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it." It foresaw a future in which machines would "use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves."

Meanwhile, the amount of sensor data, communications traffic and other kinds of information generated and conveyed by and for the military has grown to such an extent that humans can no longer assimilate, understand and act upon it all effectively. To take full advantage of this fire hose of information, warfighters, strategists and intelligence analysts have increasingly needed help from machines—not just as simple collators of facts or crunchers of numbers, but as intelligent actors able to make sense of speech, text, images, video and other complex and dynamic data streams.

THE DARPA SOLUTION

DARPA recognized early in its existence that AI could address a range of national security needs and, in response, initiated cross-disciplinary AI programs to combine advances in computer science, mathematics, probability theory, statistics and cognitive science. The goal was to automate a range of capabilities usually associated with intelligence, such as deriving new knowledge from data or experience, reaching logical conclusions and proposing explanations for observed phenomena. Initial efforts focused largely on developing computerized systems for military operations, especially in the critical domain of military command and control. DARPA quickly became a leader in AI R&D, with applications gradually expanding into fields as diverse as speech recognition and language translation, big data analytics and intelligence analysis, genomics and medicine, vision and robotics, and driverless transportation and navigation.

THE IMPACT

DARPA's early investments in the fundamentals of AI helped demonstrate that machines could, in fact, be capable of providing increasingly intelligent assistance on the basis of experience and feedback. After initial successes in command and control and other military applications, DARPA in the 1980s funded the 10-year Strategic Computing Initiative to take advantage of fast-moving advances in computer architecture, software and chip designs and propel AI technology to new heights. Among the outcomes was the Dynamic Analysis and Replanning Tool (DART), a problem-solving aid that used automated reasoning and significantly improved logistics and other planning functions during Operations Desert Storm and Desert Shield. With the help of DART, deployment plans that had previously taken four days to generate were routinely completed within hours.

DARPA's R&D in AI had a similarly revolutionary impact in another important but challenging domain:

advanced language processing. As far back as the 1970s, DARPA's Speech Understanding Research program created the first automated speech transcription systems, one of which was later commercialized by Dragon Systems. As a direct result of DARPA's targeted investments over a span of decades, machines became increasingly adept at recognizing and understanding connected speech—including text and speech in selected foreign languages. Those efforts have helped soldiers better understand local individuals and have contributed to the gathering of regional intelligence while also seeding what has become a booming commercial marketplace. This project was also notable for developing statistical models of language, presaging today's data-intensive machine learning approaches to many problems in language, vision and other areas.

In addition, through its Personalized Assistant that Learns (PAL) program, DARPA created cognitive computing systems to make military decision-making more efficient and more effective at multiple levels of command; reduce the need for large command staffs; and enable smaller, more mobile and less vulnerable command centers. DARPA worked with military users to refine PAL prototypes for operational use, and with the defense acquisition community to transition PAL technologies into military systems.

DARPA-developed AI has also proven critical to the development of driverless cars. DARPA's Grand Challenge and Urban Challenge competitions for self-driving vehicles demonstrated that machines could independently perform the complex human task of driving. Similarly, the DARPA Robotics Challenge has accelerated progress toward the development of robots capable of offering assistance during natural and man-made disasters. And DARPA's Cyber Grand Challenge (CGC), scheduled to conclude in 2016, is applying decades of

DARPA's Grand Challenge events in 2004 and 2005 and Urban Challenge in 2007 showed the potential of self-driving vehicles.

groundwork in AI to create the first-ever fully automatic network defense system—an advance that would profoundly change the risk environment surrounding today's cyber operations. Without a doubt, AI is now vital to national security.

TRANSITION

DARPA-sponsored AI technology has transitioned to numerous components of the U.S. military. Elements of DARPA's PAL program, for example, were integrated into the Army's Command Post of the Future, which integrates data from different feeds into a single display and today contributes to more timely decisions and coordinated operations on a daily basis around the world. Similarly, multiple DARPA language translation devices and systems have been deployed in conflict zones over the past decade as part of the agency's development work. These have supported warfighter interactions with local populations and the generation of regional intelligence from broadcast media and other sources.

DARPA-developed AI has also become deeply embedded in the commercial sector. Advances stemming from the agency's PAL program were applied not only for military users but also to enable voice-based interaction with civilian handheld devices. This led to the 2007 launch of Siri Inc., later acquired by Apple Inc., which further advanced and then integrated the Siri/PAL technology into the Apple mobile operating system.

Similarly, the development of Google's original search algorithms in the mid-1990s was carried out under funding provided in part by DARPA through Stanford University's Digital Library Project. Google is now leveraging the AI developed for DARPA's Urban Challenge to jump-start the field of autonomous transportation.

More generally, much of the technology that today is called big data analytics and machine learning traces its roots to earlier DARPA support, often university or other research projects that ultimately fed the many aspects of the wide field that is artificial intelligence today.

WHAT'S NEXT

DARPA continues to make game-changing investments in AI, taking advantage of rapid advances in hardware, software and communications technologies. The Agency's Big Mechanism program is developing technology to help computers read scientific and technical papers, assemble fragments of knowledge into more complete models and propose interventions to achieve specific goals. The program aims to address a seminal problem of modern science: Many processes of current interest such as cancer, brain function and climate are influenced by thousands of factors but researchers typically study and publish findings about highly specialized fragments of these processes, and no person can read all the relevant publications or integrate all the factors that together might make these processes understandable and tractable. Big Mechanism is enabling a new mode of science in which every publication immediately becomes part of a bigger picture and the transition from research to everyday reality is greatly accelerated.

DARPA's Probabilistic Programming for Advancing Machine Learning (PPAML) program aims to create user-friendly programming languages to simplify and democratize the now-arcane art of building machine-learning applications. Doing so would accelerate the development of intelligence-intensive applications, from email spam filters to smartphone personal assistants to self-driving vehicles, by obviating the need for hard-to-find experts to build custom software from scratch.

DARPA's Visual Media Reasoning (VMR) program is working to enable queries of photo content, such as "What make and model of vehicle is that?" or "Where is this building located?" VMR technology promises to serve as an intelligent force multiplier by extracting relevant information for human analysts and alerting them to scenes that warrant expert attention.

DARPA's Cyber Genome program is developing automated machine intelligence techniques for malware analysis. By clustering related malwares into representative families and generating detailed lineage graphs, Cyber Genome is revealing how hackers have modified earlier generations of malware to achieve new goals, providing timely insights into the specific purpose of newly discovered nefarious sequences. As of early 2015, three potential transition partners were evaluating Cyber Genome tools in their operational environments.

DARPA's Cyber Grand Challenge (CGC) is a competition that seeks to create automated cyber defense systems capable of reasoning about program flaws, formulating patches and deploying them on a network in real time. At present, the lengthy time window from initial vulnerability discovery to widespread patch deployment puts cyber defenders at a significant disadvantage. By acting at machine speeds and enterprise scales, CGC aims to overturn today's attacker-dominated status quo.

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